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Studies on long term durability of aluminum airframe structure made by affordable process

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SUMMARY

Affordability is one of the most important problems of today's development of airframe especially for aluminum alloy application. Some new aluminum alloys and improved processes are being applied to production cost reduction, and tests related to long term durability of applied structures are also carried out.

In this report, our recent studies of following three affordable process methods to aluminum alloy structures are introduced, these are outline of process studies and their merits, and mechanical properties, fatigue properties and corrosion resistance.

(1)Application of new 6000 series alloy of high formability
(2)Application of premium precision casting
(3)Application of superplastic forming

1. INTRODUCTION

Aluminum alloys and composites are competiting severely in the field of airframe structural material. Development of composites increases its speed now, and these are now applied to primary structures. However application of aluminum alloys seems to be maintained as major structural materials because progressive improvement of aluminum alloy and its process have been also made.

Weight reduction and cost reduction are pursued by development of new alloys and improved forming process.
Trend of improved aluminum forming process is to change complicated assembled structure to monolithic structure. These are achieved by large scale high speed machining, large panel precision forming, and relatively large size complicated precision casting and superplastic forming. Application of high cold form material may considered in this group. Target of the application of these processes are decreasing of remarkable assembly cost reduction and weight reduction by decreasing fastener and two sheet layered area for joining.

Monolithic structure or monolithic complicated part is also effective to long term durability. Free of joint means smooth load distribution and lower stress concentration level, that is good for fatigue life. And corrosion problem may be reduced because crevice corrosion and dissimilar metal corrosion etc. may be often caused around joint portion.

Our some recent studies about forming process are introduced in this report, these includes application of high form 6000 series alloy by cold working, precision casting, superplastic forming. These were examined the effectiveness of cost reduction and weight reduction by forming trial parts. Then mechanical properties and corrosion properties were examined.

2.NEW 6000 SERIES ALLOY OF HIGH FORMABILITY

2.1 Concept of the development of new alloy

A new high strength Al-Mg-Si-Cu alloy (6000 series alloy) was developed in Japan(Ref.1). Concept of this development is shown in Figure 1, this material is considered to replace the widely used 2024-T3.

Alloy 2024-T3 is one of Al-Cu-Mg alloys(2000 series alloy), and has been used as main aerospace structural material. The alloy has high strength and good resistance to fatigue crack growth. But it also has some problems in formability and the corrosion resistance. 6000 series alloys have lower strength compared with 2000 series alloys, but have some better properties like corrosion resistance, formability, lower density and lower production cost compared with those of 2000 series alloys. If the strength of 6000 series alloy is improved and the merits are maintained, the alloy may meet the requirements for the new major material. Alloy 6013 was developed with similar ideas, but tensile strength is not reached to that of 2024 –T3.

Mechanical properties and corrosion resistance were studied in some 6000 series alloys with varying amount of the alloying elements. Mainly Cu and Si were controlled, effect of them on strength is shown in Figure 2.

Finally chemical composition was fixed as shown in Table 1. This alloy is 3% lower density than 2024-T3.

2.2 Mechanical properties and corrosion properties of new alloy

Tensile and yield strength of new alloy is shown in Figure 3 compared with those of 2024-T3, 6013-T6 and 6061-T6. Tensile and yield strength of new alloy are larger than those of 6013-T6, and tensile strength is almost same as that of 2024-T3.

Figure 4 shows the comparison of fatigue crack growth rate between new alloy and 2024 –T3, these are almost same. And nearly the same fracture toughness data is obtained between new alloy and 2024 –T3.

Paper presented at the RTO AVT Workshop on "New Metallic Materials for the Structure of Aging Aircraft", held in Corfu, Greece, 19-20 April 1999, and published in RTO MP-25.

Corrosion properties of new alloy are compared with those of conventional alloys. Figure 5 shows the result of corrosion test per ASTM G-110. 2024-T3 shows very severe corrosion attack, and 6000 series alloy shows shallow intergranular corrosion. Corrosion depth of new alloy is smaller than that of 6013-T6.

Above these tests and another tests, for example, bearing test and shear test etc. show that new material is promising mechanical properties used as replacing 2024 alloy. This new alloy may have more long term durability than 2024 alloy because of better corrosion properties, and almost same fatigue crack growth and toughness.

2.3 Formability test and trial part forming results etc.

New material is formed at T4 condition and then aged to T6 condition. Formability of new alloy is compared with that of conventional alloys, hemispherical dome test and bending test were carried out. Result of hemispherical dome test is shown in Figure 6. New alloy shows larger forming height than that of 2024-T3 or 2024-W, and almost same as that of 6013-T4. And bending test shows same trend, permissible bending radius of new alloy is smaller than that of 2024-T3 or –W, and same as that of 6013-T4.

Effect of the strain of cold forming on mechanical properties of 2024-T3 is very large, but that of new alloy is small because aging process moderates cold working effect. Effect of strain on compressive yield strength is shown in Figure 7 as example.

So, this material may be useful to severe contoured panel, bead panel and curved frame etc.. Figure 8 shows bead panel of new 6000 series alloy sheet. Inspection is secured no irregular thickness nor distortion. In this case, about 50% cost reduction may be estimated by changing the design concept from assembled sheets to monolithic bead panel.

Precision extrusions and hollow extrusions of new alloy are also developed, these are shown in Figure 9. Dimension of wall thickness is able to be settled very thin. So these may be used effectively as light and high stiff components.

Another merits of this new alloy are weldable and good thermal stability of strength. For the latter property, tensile strength is a little lower than that of 2219-T8, but thermal stability of strength is rather better, because aging temperature is high. So this alloy may be applied to welded structures or high temperature structures in aluminum used field.

3. LARGE PRECISION CASTING OF ALUMINUM ALLOY

3.1 Development of casting alloy and casting process

It is spreading to apply premium-quality large size precision casting for primary aircraft structures. D357,A357 and A201, which are used as casting alloys, have good mechanical properties.

Improved casting methods such as low pressure casting enables to decrease casting discontinuities, these are casting cavities and cracks, and realizes the complicated thin casting products. And control of microstructure is important to get good strength, Figure 10 shows the effect of secondary dendrite arm spacing on strength of A357 cast alloy. Strength decreases with increase of arm spacing. Arm spacing decreases with increase of cooling rate in solidification, so chill block in a mold should be used if high strength may be secured partially in the structure.

Following heat treatment process after casting process is also important, uniform cooling rate must be requested to get distortion free and proper strength cast structure.

3.2 Mechanical properties and corrosion properties of cast alloys

Figure 11 shows the yield strength and fracture toughness of cast aluminum alloys compared with sheet or forged Al alloys. Fracture toughness of A357 is not so high compared with that of 2024 sheet, but yield strength of A357 is almost same as that of 2024-T3 sheet, and fracture toughness and yield strength of A201 alloy is almost same as that of 7075 forging. Strength of D357 is not shown, it is same as that of A357, and rather narrower strength dispersion. A357 may used to replace assembled sheet parts of 2024-T3 sheet, however applied structure must be the high stiff structure of low stress level and smooth stress distribution. A201 may be used to replace mainly 7000 series structural parts. In this report, results of A357 are introduced as follows(Ref.2).

Figure 12 shows the fatigue crack growth rate of A357 cast alloy, which inner discontinuities are permissible level examined by X ray. Crack growth rate is relatively lower than that of 2024-T3 or 7075-T6 wrought material. And Figure 13 shows the fatigue strength of A357 alloy. Fatigue strength is lower than that of 2024-T3. When single crack is propagated in the case of fatigue crack growth test, small casting cavities may trap crack tip. So crack propagation path becomes wavy, then it makes fatigue growth slow. On the contrary, many cracks are caused at casting cavities simultaneously in the case of fatigue strength test , and these cracks are joined each other. This phenomena decreases fatigue strength. When strength level is effectively low, former fracture mode of slow crack propagation from single or a few portion may be considered as structural fracture mode.

General corrosion property of A357 is said to be better than that of 2024-T3 bare sheet. And A357 does not show susceptibility of stress corrosion cracking.

Long term durability of A357 or D357 cast structure may be considered that it depends on design philosophy to fit fatigue properties. Casting structure should be designed by stiffness driven and stress in the structure should be low level.

3.3 Study of application

Application of precision casting proves advantage of the weight reduction and cost saving available when moving from complicated fabricated structures to monolithic integrated structures.

Figure 14 shows the exit door manufactured by casting for trial, size is about 600 × 620 × 70 mm and thinnest portion is $1.5mm^t$. Material is A357. And then Figure 15 shows comparison of cost and weight between precision casting and assembled structure. Thickness of casting structure must be increased compared with sheet thickness of assembled structure because of casting factor. However 10% weight reduction may be attained because there is no fastener nor two

sheets layered area for joining.
Cost may be decreased to about a half of the cost of assembled structure of sheet.

Precision casting is promising method, but designers must consider several problems of effective application when they try to apply it. These problems are special design concepts which include the knowledge of liquid metal flow and cooling characteristics in mold, weight saving design technique, and then knowledge of quality assurance concepts to casting defects. More strict contact among staff from design to qualification must be required than usual process because effect of mutual relationship among design and each process on the quality of products is stronger than usual process.

Now, D357 becomes available, and application study of casting is developed widely, and structures about 2mϕ is studied as casting application.

4. SUPERPLASTIC FORMING OF ALUMINUM ALLOY

4.1 Outline of superplastic forming method

Superplastic forming technology makes it possible to fabricate a sheet of complex configuration such as deep bulge forming, and this technology also enables to change assembled sheet parts to an integrated sheet part. Fine-grained aluminum alloys such as 7475 and 5083 alloy show superplasticity at restricted narrow range of both temperature and strain rate. Figure 16 shows the relation between testing temperature of tensile test and elongation of fine-grained 7475 alloy, which shows superplastic phenomenon at about 500℃.

Forming method used to application is generally bulge forming by air pressure, sheet to be formed is fixed in jig and sequentially controlled gas pressure to get desired strain rate is loaded at proper temperature. Smooth plastic metal sheet deformation on die must be required, so lubricating media between sheet and die is also important.

4.2 Mechanical properties of superplastically formed part

Mechanical properties are same if defects are not caused during forming. When forming condition is improper, forming is not completed or thickness distribution becomes improper.

Another problem is the generation of micro cavities as inner defects which decrease strength. Figure 17 shows the effect of the amount of cavities on tensile properties of formed 7475 alloy. When cavity area is over 1% of the examined unit area of cut section, tensile strength and yield strength and then elongation become decreased and lower than the values of specification. And Figure 18 shows the effect of the amount of cavities on fatigue properties. Fatigue strength become decreased when cavity area is also over 1% (Ref.2).

Amount of cavities depends on prepared materials and process. Microstructure etc. is secured by material specification. Amount of cavities increases with increase of elongation so, it is required not to cause partially heavy elongation by means of design modification and proper process control. Corrosion properties are not affected by the generation of cavities.

From the above, quality control about thickness distribution and amount of cavities should be important to secure long term durability of superplastically formed part and these factors depend on process. Dummy part to be adjusted severest elongation level of real part may be formed simultaneously to check the generation of cavities as sampling inspection.

4.3 Application study of superplastic forming

Figure 19 shows the trial product of superplastic forming, which material is 7475 alloy. Thickness distribution is proper and cavities are very few. Most important design requirement is structural stiffness alike casting, and it is confirmed. Many parts are integrated to one part, so about 20% production cost reduction is predicted in this case.
When designers would like to use this method, they must consider special design technique about thickness control and quality assurance method about generation of cavities etc. and strict contact with production stuff as is the case of casting.

5. CONCLUSIONS

Application of three new processes of aluminum alloys to pursue affordability are studied, these are application of high strength 6000 series alloy of high formability, large precision casting and superplastic forming. Concluding remarks are as follows.

(1)Removing joint and assembly process by using these new processes to form monolithic structure is very effective to attain total cost reduction and weight reduction.

(2)Monolithic structures by these new processes have basic merits of long term durability, that is, free of joint which cause many problems. These are crevice corrosion and dissimilar metal corrosion, then bearing fatigue strength and not smooth stress flow.

(3)New 6000 series alloy developed in Japan has good mechanical properties to replace 2024-T3 alloy. Fatigue strength and corrosion properties are also good.

(4)Structural stiffness is often most important design requirement for the application of precision casting and superplastic forming. Fatigue strength properties of structure applied these two methods are good if design is fair and inner discontinuities are proper low level.

(5)These new forming methods often require new design concept and new qualification method etc. So, more strict contact among staff of design, material, manufacturing and qualification is required.

6. REFERENCE

1. H.Uchida et al, The 5 th. ICAA, p.1758(1996)
2. H. Hira et al, Kawasaki Tec. Review, No.111,p.18 (1991).

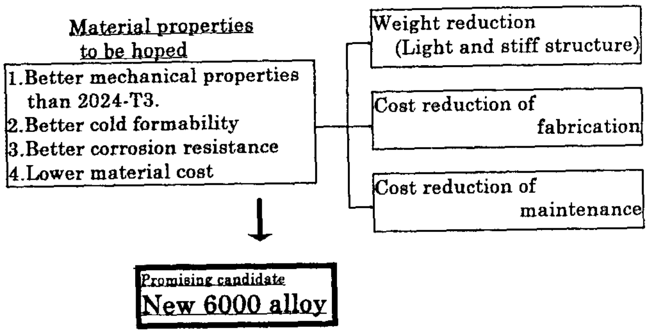


Figure 1 Concept of the Development of New 6000 Series Alloy

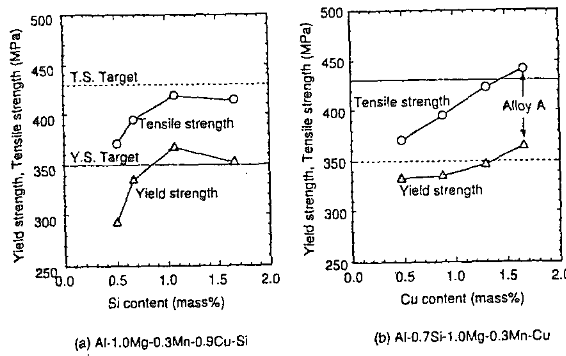


Figure 2 Effect of Silicon and Copper Content on Strength of Al-Mg-Si-Cu Alloys

Table 1 Chemical Composition of New 6000 Series Alloy (mass%)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.75	0.14	1.64	0.01	1.01	0.15	0.01	0.02	bal.

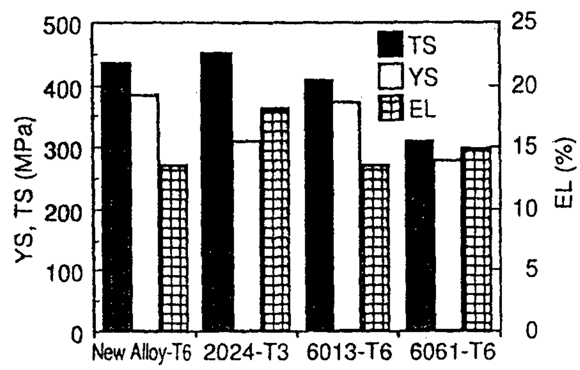


Figure 3 Mechanical Properties of New Alloy and Conventional Alloys (Thickness:1.27mm)

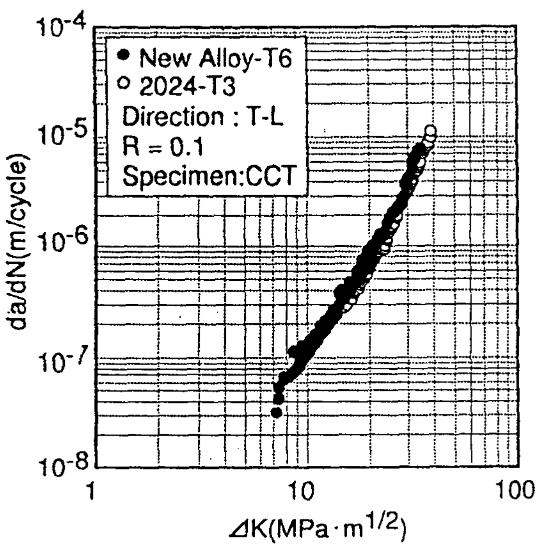


Figure 4 Comparison of Fatigue Crack Growth Rate between New Alloy and 2024-T3 (Thickness:1.27mm)

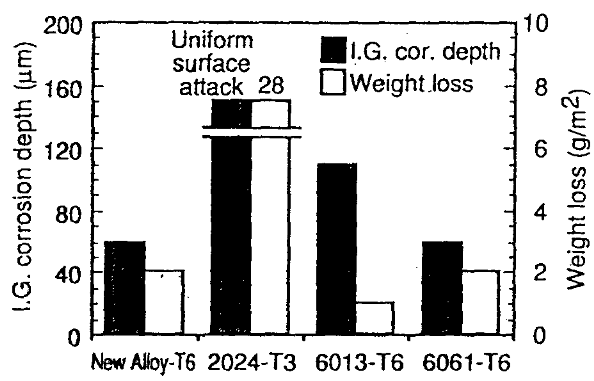


Figure 5 Intergranular Corrosion Depth and Weight Loss of New Alloy and Conventional Alloys (ASTM-G-110)

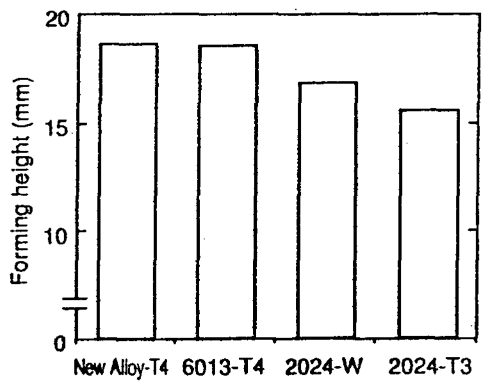


Figure 6 Comparison of Hemispherical Dome Test of New Alloy and Conventional alloys (50mm Diameter)

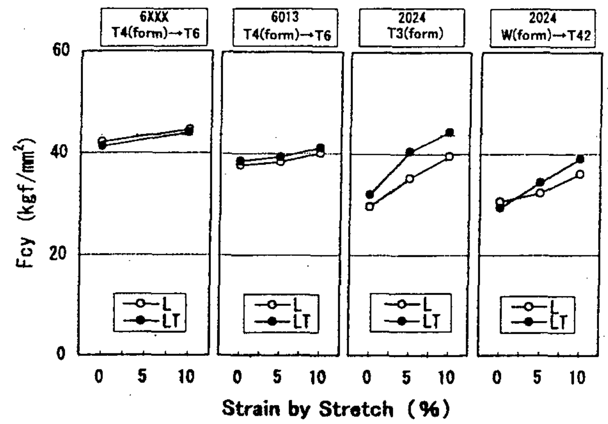


Figure 7 Effect of Strain by Stretching on Compressive Yield Strength of New Alloy and 2024 Alloy

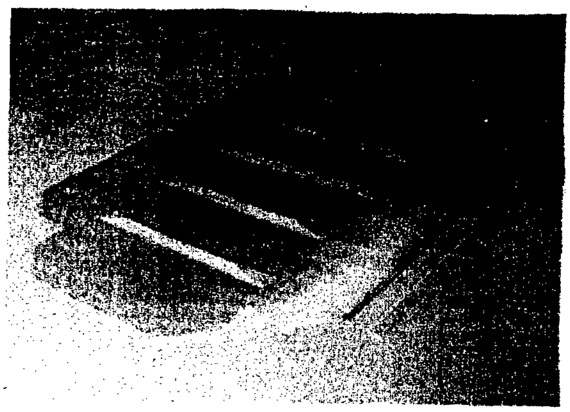


Figure 8 Bead Panel Trial Part of New Alloy (Bead Height:8mm,Width:27mm)

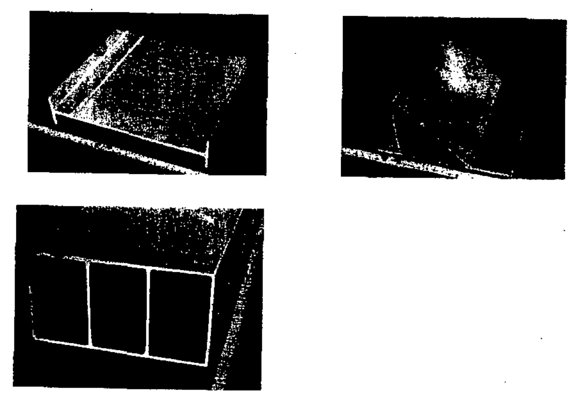


Figure 9 Precision Extrusion and Hollow Extrusion of New Alloy

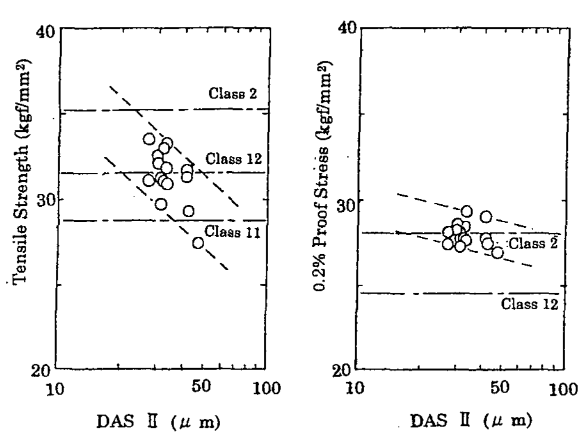


Figure 10 Effect of the Secondary Dendrite Arm Spacing (DAS Ⅱ) on Tensile Properties of A357 Cast Alloy (Strength Class: from MIL-A-21180)

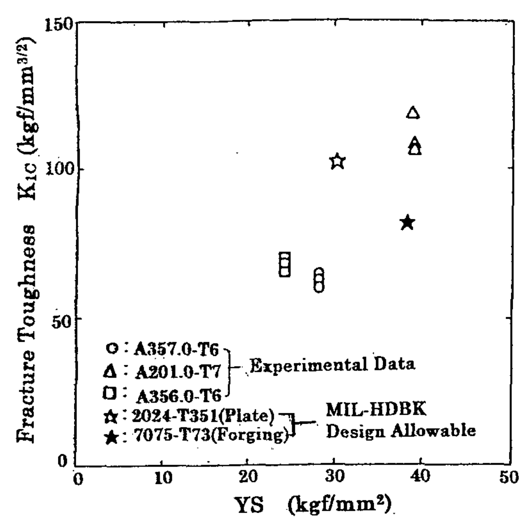


Figure 11 Relationship between Tensile Yield Strength and Fracture Toughness of Aluminum Cast Alloys and Conventional Wrought Alloys

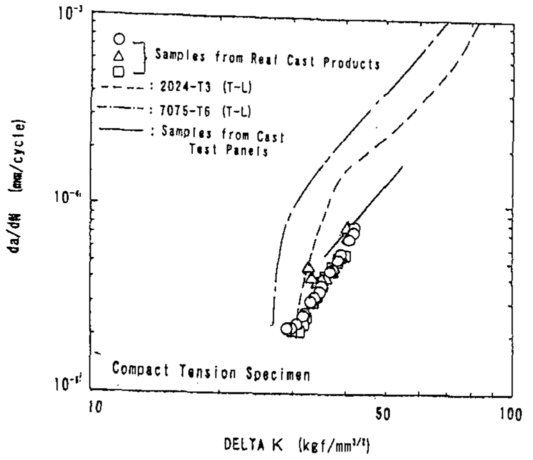


Figure 12 Fatigue Crack Growth Rate of A357 Cast Alloy Compared with That of Wrought Alloys

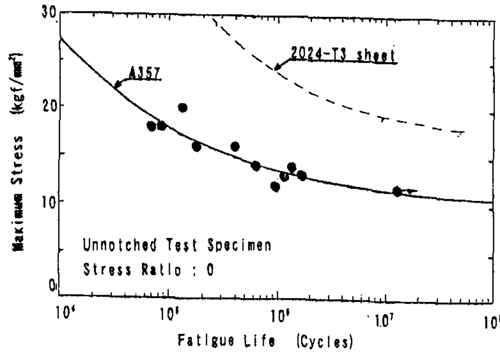


Figure 13 Fatigue Strength of A357 Cast Alloy Compared with That of 2024-T3 Sheet

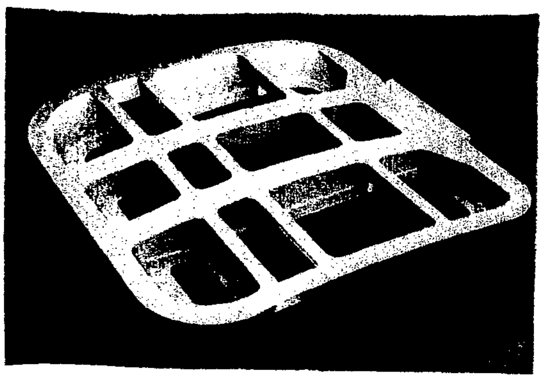
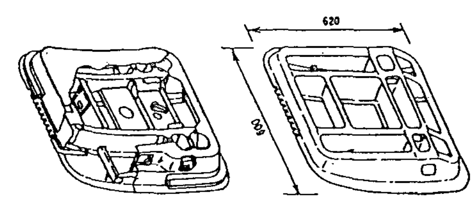


Figure 14 Exit Door Manufactured by Casting for Trial (Material: A357)



	Estimated weight (%)	Estimated cost (%)
Assembled structure of sheet	100	100
Precision casting	91	53

Figure 15 Comparison of Predicted Cost and Weight between Precision Casting and Assembled Structure

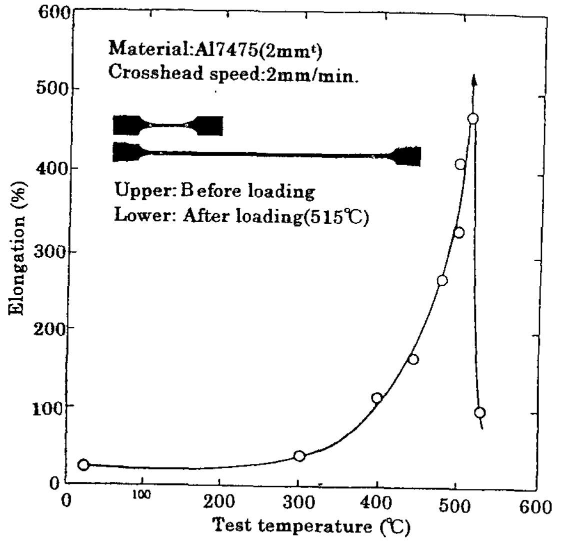


Figure 16 Superplastic Phenomenon of Fine- grained 7475 Alloy

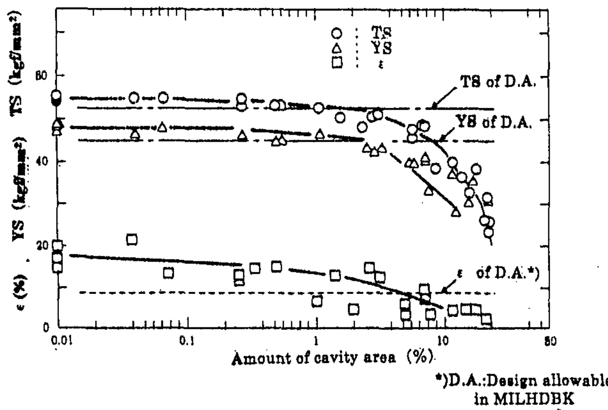


Figure 17 Effect of the Amount of Cavities on Tensile Properties of Superplastically Formed 7475 Alloy (Heat Treated to T6 after Forming)

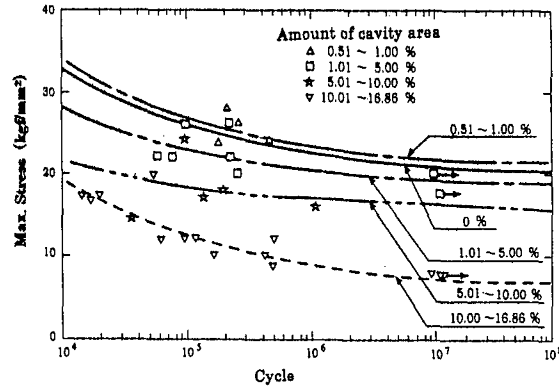


Figure 18 Effect of the Amount of Cavities on Fatigue Strength of Superplastically Formed 7475 Alloy (Heat Treated to T6 after Forming)

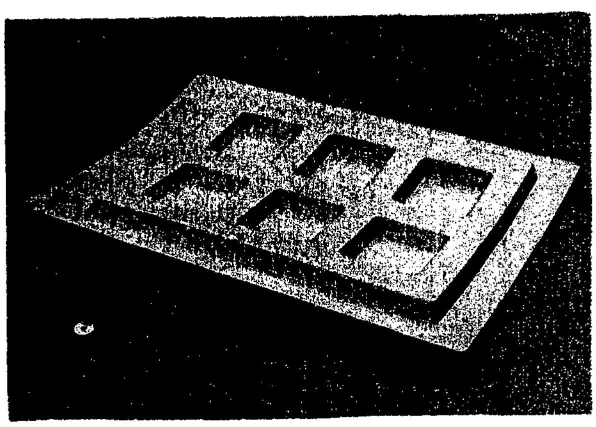


Figure 19 Trial Product of Superplastic Forming